



TITLE:

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Study of Plasma Behavior during ECRH Injection in the GAMMA 10 SMBI Experiments

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Abstract. Establishment of fueling system is one of the critical issues for the future fusion reactors. Fueling experiment supersonic molecular beam injection (SMBI) have been carried out in the central-cell of GAMMA 10. In GAMMA 10, electron cyclotron resonance heating (ECRH) is used at plug/barrier-cells for the formation of the axial confining potential. Recently, ECRH was applied during SMBI to plug the loss particles and increased the plasma density in the central-cell compared to without ECRH. This result suggests that the particles are confined during SMBI due to the injection of ECRH at plug/barrier-cells in GAMMA 10.

Keywords: GAMMA 10, supersonic molecular beam injection, high density plasma formation, ECRH.

1. Introduction

Optimization of fueling control in the magnetically confined plasmas enables the profile control of the core plasma density as well as reduction in neutral particles in the peripheral area. For example, ice-pellet injection [1, 2] is effective in increasing the density in the plasma core region, while gas puffing [3, 4] is suitable to control the density in the edge region including the divertor. The ice-pellet injection is characterized by a high fueling efficiency however, it is successful in large devices. Supersonic molecular beam injection (SMBI) developed by L. Yao et al. [5], is suitable for the control of edge-localized-mode in ITER-like tokamaks [6]. SMBI gives high-speed and highly-directive gas injection system which can inject neutral particles deeper into the core-plasma. In order to understand the mechanism of the high fueling efficiency of SMBI, many experiments have been carried out in many devices, such as HL-2A tokamak [7, 8], Heliotron J [9, 10], NSTX [11], JT-60U [12], Tore Supra [13], EAST tokamak [14] and Large Helical Device [15].

In order to form high- β plasma in the mirror device, it is an important issue to increase the plasma density in the main plasma region. Recently, fueling experiment by SMBI has been started to increase



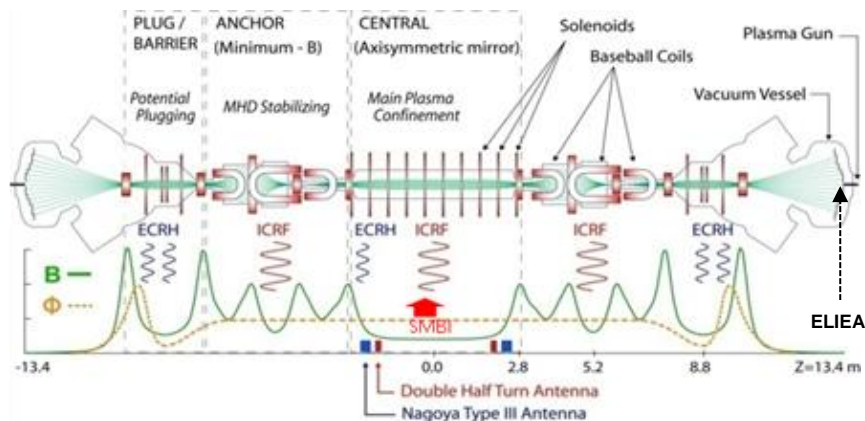


Fig.1 Schematic view of GAMMA 10 and axial profile of magnetic field strength B and potential together with location of SMBI system and ELIEA.

the plasma density in the main plasma confinement region of the GAMMA 10 tandem mirror [16-18]. GAMMA 10 is the world largest tandem mirror device which is axisymmetrized minimum-B anchored with thermal barrier at both mirror ends [19, 20]. In GAMMA 10 SMBI has been applied in the central-cell and has enabled to obtain high density plasmas in the central-cell (NLcc) as compared with the conventional gas puffing. It inputs a large amount of gas in only a short time. The increase in the amount of gas in the central-cell increases the plasma density. Therefore, more ions flow into the end-cells, and the ion-current density is increased during SMBI. Electron cyclotron resonance heating in plug/barrier region (P/B-ECRH) has been applied in GAMMA10 for the formation of the axial confining potential to plug the lost particles and has been observed an increase in the central-cell electron density [21]. In this case, it has been observed that a reduction in the lost-ion flux escaping from the main confining region to the both mirror ends. Therefore, it is important subject to investigate the effect of P/B-ECRH in the SMBI fueled plasmas and its response to the end-loss ions. In this study, we applied the central-cell SMBI in the P/B-ECRH plasmas to study the effect of ECRH to the plasma parameters. The response of the SMBI to the end-loss ions is investigated in the P/B-ECRH plasmas.

2. GAMMA 10 and Experimental setup

A schematic view of GAMMA 10 tandem mirror together with heating is shown in Fig. 1. The total length of GAMMA 10 is 27 m. It consists of central-cell, anchor-cells, plug/barrier-cells and end-cells. The main confinement region of GAMMA 10 is the central-cell ($Z = -300 \sim +300$ cm). The initial plasma produced by the plasma gun is heated by ICRF waves and confined by magnetic mirror field and electrostatic potential. Two choke coils and ten pancake coils are installed and formed the simple axisymmetric magnetic mirror configuration in the central-cell. The both ends of central-cell are connected to east/west anchor-cells, which keep the plasma stably. Three baseball coils are installed and form the average minimum-B configuration in each anchor-cell. The outside of anchor-cells are connected to east/west plug/barrier-cells, in which plug potential and barrier potential are produced. East/west end-cells are located to the outside of plug/barrier-cells in which the plasma flow out. The end-cells are at the very end of GAMMA 10 where end-loss ion energy analyzer (ELIEA) is installed to measure the end-loss ion current density. SMBI is very simple system, where high-pressure hydrogen gas is ejected through a fast solenoid valve equipped with a Laval nozzle. In GAMMA 10, SMBI system has been installed in the central-cell at $Z = -14.5$ cm. In the experiment, the plenum pressure is varied from 0.3 MPa to 2.0 MPa and the pulse width is usually 0.5 ms.

3. Results and discussion

In the experiment, SMBI pulses were injected into the typical plasmas heated by ICRF and ECRH. SMBI pulse is injected at 150 ms and the pulse width is 0.5 ms. The electron line-density is increased

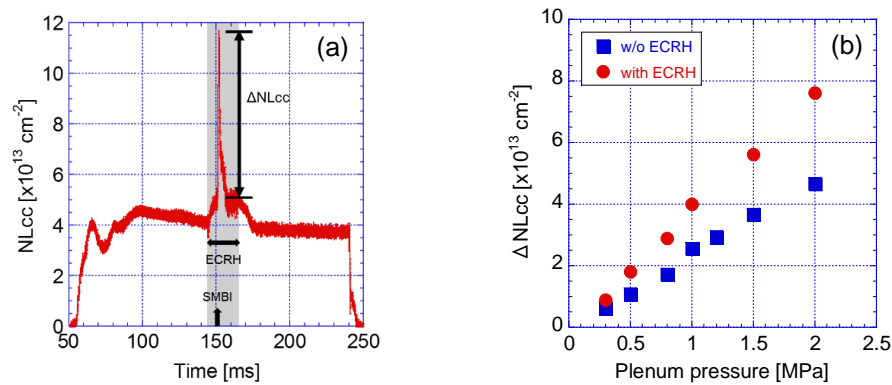


Fig. 2 (a) Temporal behavior of electron line density and (b) comparison of change in electron line density during SMBI with ECRH and without ECRH case.

during SMBI. Figure 2(a) shows the temporal behavior of NLcc during SMBI with P/B-ECRH injection. P/B-ECRH injected at 145 ms and duration is 20 ms and SMBI is injected during ECRH injection. P-ECRH and B-ECRH power are 150 kW and 100 kW, respectively. Figure 2(b) shows the change in electron line-density during SMBI with ECRH and only ICRF heated plasma. From this figure it is observed that in both the ICRF and ICRF/ ECRH plasmas, the change in the electron line-density in the central-cell increases almost linearly to the plenum pressure. From the previous study, it has been obtained that the directivity of the SMBI gas improved when the plenum pressure was up to 1.0 MPa and it saturated more than 1.0 MPa [17]. In such the case, the change in the electron line-density is almost proportional to the change in the $\text{H}\alpha$ intensity whose sightline observes the SMBI gas. These results indicate that the particle source produced by SMBI has a contribution to the increase in the electron density without saturation under the present experimental condition. Note that, in all plenum pressure cases, the change in electron line density is higher in the case of ECRH injection than the ICRF heated plasma. It implies that the particles are confined in the central-cell due to P/B-ECRH injection in the plug/barrier region.

In order to measure the end-loss ion current, ELIEA is installed on both end sides in GAMMA 10. The end loss ion current is measured by using sweep repeller voltage. Figure 3(a) shows that the end-loss

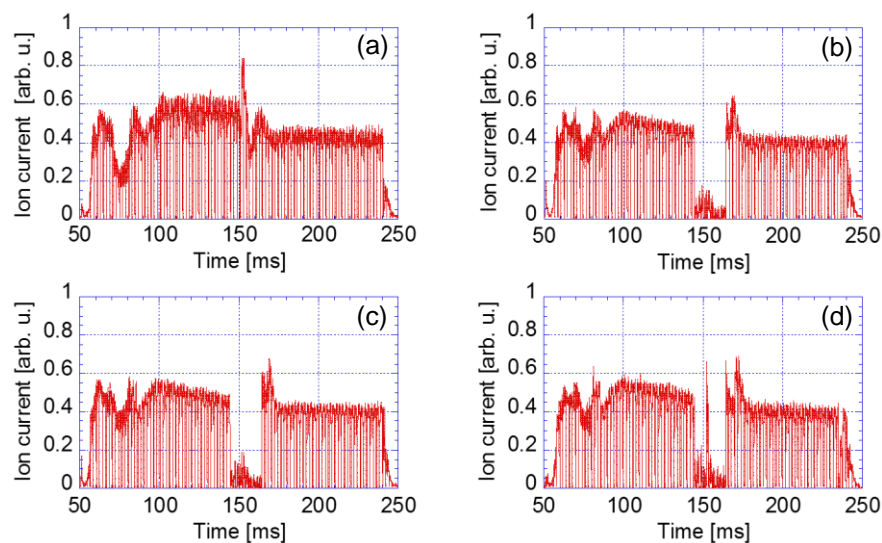


Fig. 3 (a) Temporal behavior of end-loss ion current (a) SMBI without ECRH at 1.0 MPa, (b) SMBI with ECRH at 1.0 MPa, (c) SMBI with ECRH at 1.5 MPa and (d) SMBI with ECRH at 2.0 MPa.

ion current is increased during SMBI at plenum pressure 1.0 MPa. SMBI inputs a large amount of gas within a short period of time. The plasma density increases in the central-cell due to the increase in the amount of gas. Therefore, more ion flow into the end-cells, and the ion current density is increased during SMBI. In order to plug the particles escaped from central-cell to end-cells, P/B-ECRH is applied to ICRF heated plasma. Therefore, the end-loss ion current is reduced and increases the plasma density in the central-cell during SMBI at plenum pressure 1.0 MPa as shown in figure 3(b). It might be due to the formation of plug and thermal barrier potential by P/B-ECRH in the plug/barrier region. However, SMBI at high plenum pressure (~ 2.0 MPa), the P/B-ECRH could not suppressed the end loss current remarkably. At high plenum pressure the amount of gas is high therefore the end-loss ion current density is high which could not be suppressed by this low power of ECRH system.

4. Summary

SMBI experiment has been performed in the central-cell during ECRH injection. Experimental results implies that the electron line-density is increased during SMBI with ECRH due to the confinement of particles in the central-cell. The end-loss ion current is suppressed at low plenum pressure by the production of plug/barrier potential in the plug/barrier region and increases the plasma density in the central-cell. In future, we will apply high ECRH power to suppress the end-loss ion current at high plenum pressure and increase the plasma density in the central-cell.

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